A SEMI-QUANTITATIVE GEOSPATIAL POLLUTANT-SPECIFIC EXPOSURE METRIC FOR USE IN HEALTH STUDIES ASSOCIATED WITH UNCONVENTIONAL NATURAL GAS DEVELOPMENT (UNGD) IN PENNSYLVANIA

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Abstract

Unconventional natural gas development (UNGD) within the Marcellus Shale gas play is a rapidly expanding industrial process currently impacting many areas in Pennsylvania (PA) and often occurs in close proximity to residential areas. Concerns have been raised about whether such activities represent a hazard to human health, and several epidemiologic studies have associated residential proximity to adverse birth outcomes, asthma exacerbations, cancer risk, and other untoward health effects. Emission of various air pollutants during UNGD is one possible factor in these effects; however most, if not all, of these studies have gauged exposure indirectly based on distance from and density of nearby facilities or have made limited measurements in only a few locations. Thus, establishing associations to specific chemical exposures and dose-response relationships have proved problematic. It is currently impractical to measure individual exposure to specific chemicals over long periods of time in enough locations for use in large population health endpoint studies. We are utilizing pollutant- and facility-specific emission inventories available from the PA-DEP to create semi-quantitative geo-spatial exposure maps relating to gas development for the entire state of PA over the years 2012 – 2016. First, the latitude and longitude for all reported Marcellus-related facilities were obtained and geo-located using Arc-GIS. Three concentric buffer zones of expanding diameter of 1, 2, and 3 miles were created around each facility. Volatile organic compounds (VOC) emission values were initially chosen as the pollutant of interest since they have high specificity for oil and gas activities, but we have also begun to similarly consider emission levels of additional contaminants such $PM_{2.5}$ and NO_2. The total reported annual VOC emission value (X) for a given year was arbitrarily assigned to the inner-most buffer zone of each facility. Pollutant values assigned to areas progressively more distant from the facility were adjusted based on presumed dilution as a function of surface area (d = 2 mile, X/4; d = 3 mile, X/9). When overlap occurred between buffers corresponding to different facilities the pollutant value assigned to the overlapped shape was a function of the sum of the pollutant values from each corresponding zone contributing to the overlap. For comparative purposes, when possible, UNGD facilities were designated as single well pad, multi-well pads, and downstream processing facilities such as compressor stations. The top ten industrial point emitters of VOCs from non-Marcellus sources in each county were also similarly analyzed. Exposure maps for VOCs for each year of Marcellus inventory reporting were obtained. We have noted that considerable variability exists between different facility types. For example, compressor stations appear to emit substantially more VOCs, $PM_{2.5}$, and NO_2 than UNGD wells. Moreover, even within a single facility type considerable heterogeneity exists and is often manifest as non-normal distribution characterized by a relatively small number of high emitting facilities. Thus, simple proximity distance-weighting of a residence in relation to UNGD facilities without consideration of emission differences is likely a poor surrogate for specific chemical exposure. It is anticipated that this approach can yield a useful tool which can then be applied to environmental epidemiologic studies along with geo-coded patient/subject residential addresses in order to more specifically assign a chemical- and temporal-specific semi-quantitative exposure metric and evaluate exposure-response relationship to various disease endpoints.

Introduction

- **PA is currently the second largest producer of natural gas in the United States in large part due to rapid expansion of unconventional drilling techniques into the Marcellus Shale.**
- **Release of various chemical contaminants into air and water raises concerns that UNGD poses a health hazard for those living close to oil and gas facilities. Several studies have associated an increase incidence or risk of a variety of adverse health effects with proximity to UNGD facilities (1-4).**
- **However, lack of quantitative chemical-specific exposure information impedes the investigation of potential causal associations between this growing exposure and adverse health effects.**

Hypothesis: Facility-specific emission inventories of various air pollutants may provide a basis to develop a semi-quantitative exposure metric for use in health effect studies.

Materials & Methods

UNGD in Pennsylvania refers primarily to horizontally-drilled and hydraulically fractured wells in the Marcellus Shale, as well as associated facilities such as compressor stations required for processing and pressurization during transport. Air pollutant emission data for these sites are publically available as annual inventories published by the PA-DEP's Bureau of Air Quality (5). The inventories contain operator-reported pollutant-specific emission values for each facility in the Marcellus Shale. Emissions are divided into various source types (ie. fugitive emissions, pump, engine, heaters, etc.) and for our purposes all sources for a given facility were summed together to create a single emission value for each site. For mapping, VOC emissions were chosen since they have a high specificity for oil and gas development. In addition, $PM_{2.5}$ and NO_x were considered for quantitative comparison of facility types in select counties. Inventories include geographic coordinates for every facility. Using ArcGis Pro, the coordinates were plotted, and a different map was created for each year from 2012-2015. This time span was chosen based on the availability of data and represents a period in which there were an increasing number of active wells throughout the state (n=3373, 4154, 4987, 5374, respectively for 2012-2015). The number of compressor stations also increased over this time (n=336, 291, 380, 507). In addition to Marcellus-related facilities, we used the industrial facility emission inventory from PA-DEP (5) to identify the ten point-source facilities with the greatest annual VOC emissions per county and added them and their emissions to the map for comparison. In many cases, facilities from the Marcellus Inventory were amongst this county top ten list.

Working in ArcGIS Pro, three concentric buffers were created around each coordinate point, with increasing diameters of 1, 2, and 3 miles (each buffer zone does not include the area of smaller buffer(s) contained within creating 2 rings and one circle for each site rather than three stacked circles). The innermost buffer was assigned the annual VOC emission value of the facility at that point (X). Assuming a dilution of the emission value as a function of surface area, the middle buffer zone was assigned the value of x/4, and the outermost the value of X/9. Many areas contain a very high density of facilities creating considerable overlap of the buffer zones. Using the Intersect Geoprocessing Tool, the unique overlapping shapes were calculated, and assigned an emission value that represents the sum of the emission values from each corresponding zone contributing to the overlap. The result is a shapefile of polygons that contains both overlapping and non-overlapping buffers and a single exposure metric value for each polygon. This format would be helpful in epidemiologic studies that have access to patient/subject geo-codeable addresses that can easily be plotted and assigned the exposure metric corresponding to emission polygon in which they fall.

Results

Exposure Model based on PA-DEP reported VOC Emission Inventory

A. Creation of arbitrary exposure zones around a single UNGD facility.

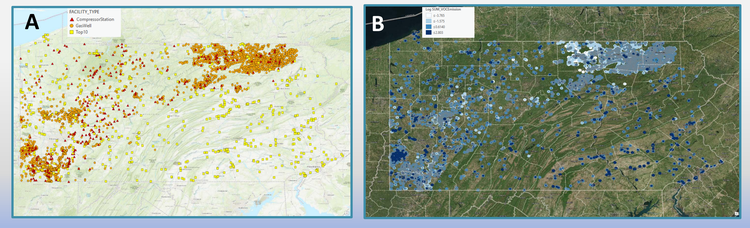
B. Summation of exposure metrics with overlapping zones from multiple facilities.

C. A high-density well area in Washington County (2013) with complex overlapping zones and exposure metrics approaching that of major industrial point sources.

VOC Exposure Metric Map for PA in 2013

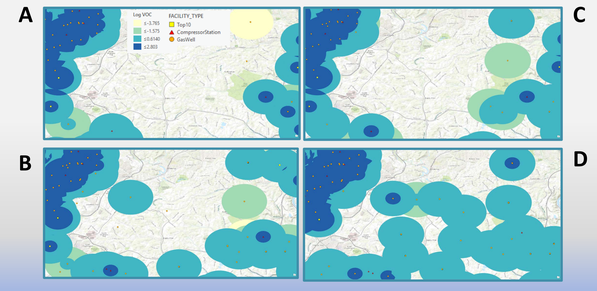
A. Map of all UNGD wells, compressor stations, and top ten industrial point source emitters from each county in PA.

B. VOC exposure metric map from all combined sources in A.

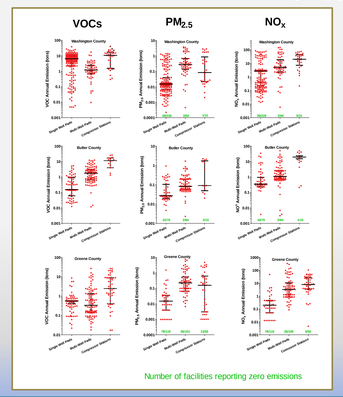


Annual Variation in VOC Exposure Metrics over 2012-2015

A 11 x 16.5 mile section of Washington County in SW PA showing evolution of exposure metrics from UNGD over time. A = 2012, B = 2013, C = 2014, D = 2015



Heterogeneity in Reported Emissions Between and Within Facility Types.



Advantages and Limitations of Exposure Metric Modeling Using Emission Inventories

Advantages	Limitations
A semi-quantitative exposure metric for any location	Assumes a uniform release over time
Captures pollutant specificity and facility variability	Does not take into account varying meteorological/geographical patterns
Suitable for longer-term health endpoints	Relies on accuracy of emission reporting
Temporal variability can be evaluated on an annual basis	Some model assumptions (exp., linear dilution with distance) can be refined with empirical evidence
	Semi-quantitative exposure metric not useful for traditional risk screening and assessment

Conclusion

- **We have constructed a semi-quantitative geo-spatial exposure metric model for VOCs produced by UNGD and other industrial facilities in PA using publically-available emissions inventories.**
- **Considerable variability in emissions, and presumed exposure, is evident both within and between different classes of facilities.**
- **Time periods for exposure can be captured on an annual basis.**
- **Application of such exposure maps for VOCs, as well as other pollutants, can provide exposure metrics for patient/subject residential addresses or other locations that may assist in epidemiological studies of human health effects and their relationship to air pollutant exposure from UNGD and other industrial activities.**

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